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Evolving Role of Lumbar Decompression: A Narrative Review

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ABSTRACT

Traditional open lumbar decompression techniques have long been used to relieve spinal canal pressure caused by lumbar spinal stenosis. However, these procedures are associated with significant postoperative pain and prolonged recovery. Over the past few decades, there has been a shift toward minimally invasive surgical (MIS) techniques designed to minimize tissue trauma, postoperative pain, and recovery time. These advancements represent a major step forward, offering smaller incisions and direct visualization of the spinal canal. Despite the clear benefits of MIS and endoscopic techniques, they also present challenges such as a steep learning curve for surgeons and a risk of incomplete decompression. The present review examines the historical progression from open to MIS and endoscopic lumbar decompression techniques, assessing their clinical outcomes, benefits, and limitations. It highlights the ongoing need for careful application of these methods based on individual patient factors and emphasizes the importance of balancing innovative techniques with evidence-based practices to enhance patient care in spine surgery. The future of lumbar decompression will likely be shaped by further technological advancements, including navigation systems, robotic assistance, and augmented reality, which promise to improve surgical precision and outcomes.

Lumbar Spine

Keywords: endoscopic spine surgery, lumbar decompression, minimally invasive surgery, spinal stenosis, surgical techniques

INTRODUCTION

Lumbar spinal stenosis represents a substantial proportion of surgically managed spinal pathologies, particularly among the aging population.[1] Among operatively managed cases, direct lumbar decompression techniques (ie, laminectomy, laminotomy, laminoplasty, and foraminotomy) have emerged as a foundational treatment paradigm, offering less invasive approaches under select circumstances, as low-grade degenerative lumbar spondylolisthesis, relative to procedures involving fusion.[1–4] Therefore, the capacity to minimize surgical invasiveness within lumbar decompression procedures has been a point of interest for ongoing research.

Over the past few decades, the landscape of lumbar decompression techniques has witnessed substantial evolution marked by the gradually increasing popularity of minimally invasive surgical (MIS) techniques compared with conventional, open decompression procedures. Traditionally, open decompression requires extensive dissection and retraction to access and decompress affected spinal segments.[5–7] The advent of MIS techniques, propelled by surgical innovation and refinements in technical expertise, has engendered approaches to minimize tissue trauma, reduce postoperative pain, and accelerate functional recovery.[8,9] Additionally, the introduction of endoscopic spine surgery represents a further advancement, employing minimal incisions and specialized instruments for direct visualization and decompression of the spinal canal, lending a promising prospect to further refine clinical outcomes.[10–12]

Despite the seemingly apparent benefits of MIS and endoscopic techniques, their adoption must be approached judiciously. Challenges such as a steep learning curve for surgeons, limited visualization of the surgical field, and the potential for incomplete decompression highlight the need for careful patient selection and surgeon expertise.[13–16] Moreover, the long-term outcomes and comparative effectiveness of these techniques vs traditional approaches remain areas of active investigation.[17,18] By critically examining the evolution of lumbar decompression techniques, from open to minimally invasive and endoscopic methods, this review aims to shed light on the progress achieved thus far and the considerations necessary for future advancements. This historical perspective underscores the importance of balancing innovation with evidence-based practice to ensure that new techniques provide tangible benefits over established methods, ultimately enhancing patient care in the field of spine surgery. A general overview of open and minimally invasive lumbar decompression techniques is provided in Table 1.

OPEN LUMBAR DECOMPRESSION

Laminectomy

Laminectomies constitute 1 of the most common procedures used to achieve lumbar decompression, classically involving the removal of the lamina and spinous process lateral to the medial component of the facet joint at the impacted level.[19] The first lumbar laminectomy was performed in 1814 by Henry Cline through an open approach, marking the foremost modern attempt at achieving spinal decompression.[33] Confined by poor aseptic techniques and limited anesthetic capabilities, the procedure invariably failed. In 1829, however, Alban Gilpin Smith performed the first successful bilateral laminectomy to address a traumatic disc rupture.[34,35] Following this historical milestone, open bilateral laminectomies became a foundational technique for lumbar decompression.[35,36] In 1910, Alfred Taylor introduced a less invasive derivative, an open unilateral laminectomy, as an evolution of its bilateral counterpart.[37] Thereon, open unilateral approaches became the customary decompression technique practiced throughout the early and mid-1900s.[38]

Laminoplasty

Laminoplasty has become 1 of the preferred methods for posterior decompression and is generally considered a safe and reliable procedure.[39] Developed by Japanese orthopedic surgeons in the 1970s and 1980s to counteract limitations with posterior laminectomy in the cervical spine, including intraoperative spinal cord injury, formation of a "laminectomy membrane," and postoperative progression of cervical kyphosis, this technique has gained widespread popularity due to its minimally invasive approach, decreased postoperative pain, and lower risk of postoperative deformity compared with traditional laminectomy.[40,41]

Laminoplasty has evolved through 4 primary techniques: Z-shaped (1968), open-door (1977), en-bloc (1978), and double-door or "French-Door" (1982).[42–45] While these techniques were originally developed to treat cervical spine pathology, many of them have been adopted to treat lumbar pathology as well. Introduced in 1981, lumbar laminoplasty aimed to circumvent the iatrogenic instability and tissue damage that often resulted from conventional laminectomies. In the late 1980s and 1990s, several studies comparing outcomes of open lumbar laminoplasty with conventional laminectomies found lower reoperation rates within 4 years for patients who underwent laminoplasty, but at the cost of increased operative time and blood loss, suggesting its benefits were mainly for younger patients with lumbar stenosis.[20,46,47] When comparing various laminoplasty techniques, to date, no particular method of laminoplasty has yielded superior results. Especially in the lumbar spine, data comparing postoperative outcomes between the variations remain sparse.[48,49]

In most cases, laminoplasty and laminotomy may be used interchangeably when treating posterior cord compression. A systematic review and meta-analysis performed by Sun et al suggests that laminoplasty may be preferable over laminectomy due to decreased blood loss, quicker recovery, shorter length of stay (LOS), lower rates of spinal deformity, and reduced cerebrospinal fluid leakage, without impacting operative time or tumor resection rates.[50] However, these findings must be taken with caution considering that limited high-quality data exist comparing these various techniques.

Laminotomy

Laminotomies present an alternative decompressive technique to relieve stenosis by either unilateral or bilateral removal of the upper part of the inferior lamina and the lower portion of the superior lamina.[21] The first cited case of a laminotomy was described in the early 20th century by Hermann Oppenheim, who proposed the use of a partial laminectomy. By the 1980s, laminotomies began to be recognized as a viable alternative to laminectomies, offering the advantages of decompression of the affected area while preserving posterior structures.[22,51,52] By preserving the supraspinous ligament, interspinous ligament, and spinous process intact, postoperative weakness associated with paraspinal denervation is minimized, and midline spinal elements vital for spinal stability are maintained.[51,52] Unlike laminectomies, laminotomies involve reduced disruption of the surrounding biomechanics and anatomy of the spine.[53] The reduced invasiveness of laminotomies mitigates the risk of iatrogenic mechanical instability and has the potential to obviate the need for subsequent operative interventions when appropriately indicated.[54]

Research evaluating postoperative outcomes has shown that laminotomies yield similar clinical outcomes to those of laminectomies. In a large prospective study conducted between 1985 and 1987, it was found that patients

Table 1. Summary features of lumbar decompression techniques.[19–32]

Procedure	**Summary Features**
Laminectomy	Indications ● Symptomatic spinal canal stenosis that does not respond to conservative treatment ● Rapidly progressing neurological deficits or intolerable pain ● Cauda equina syndrome Contraindications ● Patients with multiple medical comorbidities including depression ● Scoliosis ● Spondylolysthesis ● Lateral listhesis Approaches ● Open Advantages ● High success rate with significant alleviation of preoperative symptoms ● Low rate of postoperative complications that continues to reduce with the implementation of less invasive approaches Disadvantages ● Potential iatrogenic disruption of posterior structures and anatomy/biomechanics of spine ● May require concomitant fusion
Laminoplasty	Indications ● Symptomatic stenosis without any signs of significant instability Contraindications ● Severe osteoporosis or active infection ● Significant instability requiring fusion Approaches ● Open Advantages ● Posterior spinal structures preserved ● Reduced risk of postoperative spinal instability and deformity Disadvantages ● Limited literature looking at long-term outcomes of lumbar laminoplasty compared to other procedures ● Greater risk for nerve root injury intraoperatively ● Longer operative time
Laminotomy	Indications ● Spinal stenosis with neurological symptoms ● Multilevel spondylotic lateral canal stenosis ● Lateral recess stenosis secondary to disc herniation Contraindications ● Severe instability necessitating fusion ● Pan-canal or central stenosis ● Severe facet joint arthritis or osteoporosis Approaches ● Open, minimally invasive, endoscopic (includes inside-out, outside-in, contralateral techniques) ● Unilateral and bilateral Advantages ● Reduced risk for iatrogenic mechanical instability and prolonged recovery when compared to laminectomy ● Superior preservation of posterior spinal structures Disadvantages ● Limited extent of decompression when compared to laminectomy ● May not fully alleviate central canal stenosis
Foraminotomy	Indications ● Foraminal stenosis with compression of neural structures Contraindications ● Severe spinal instability (e.g., scoliosis, spondylolisthesis, kyphosis) necessitating fusion ● Significant neurological deficits requiring more extensive decompression ● Active infection or severe osteoporosis Approaches ● Open, minimally invasive, endoscopic (includes transforaminal and laser assisted endoscopic foraminotomies) Advantages ● Preserves lamina integrity ● Potential postoperative improvement of both foraminal diameter and height Disadvantages ● Risk of nerve injury ● Reduced access to central canal leading to potential risk for incomplete decompression and symptom recurrence

Table 1. Continued.

Procedure	Summary Features
Percutaneous Minimally Invasive Lumbar Decompression (MILD)	Indications ● Stenosis secondary to ligamentum flavum hypertrophy ≥2.5 mm ● Typically reserved for patients with multiple medical comorbidities making them high-risk candidates for traditional procedures Contraindications ● Previous spinal surgery ● Infection at the site of potential surgery Approaches ● Percutaneous approach through a small incision ● Performed utilizing local anesthesia with the assistance of fluoroscopic guidance Advantages ● Is safe for patients with comorbidities that make it challenging to tolerate traditional spinal surgery such as laminectomy and laminotomy ● Does not require general anesthesia ● Minimally invasive, avoiding large incisions and lamina removal Disadvantages ● Limited decompression compared to traditional surgical method ● Limited evidence and literature available showing long-term efficacy

undergoing laminotomies experienced a 90.1% rate of symptom relief compared with 80%–90% for traditional laminectomies.[23] Further investigations have demonstrated that laminotomies yield comparable pain reduction, postoperative stability, and range of motion to laminectomies.[24,53,54] The incidence of common procedural complications, such as neural injury, infection, durotomies, and epidural hematomas, remains similar between patients undergoing either laminectomies or laminotomies.[53] Laminotomies are a viable option for patients presenting with multilevel spondylotic lateral canal stenosis, who may have equal or greater levels of symptom relief through multilevel laminotomies when compared with a traditional laminectomy. However, for those patients presenting with pan-canal or central stenosis, partial decompression offered by laminotomies would not be sufficient and would necessitate a full laminectomy. The high success rate of laminotomies along with the reduced impact to midline spinal elements offer a less invasive but equally efficacious surgical approach in relieving symptoms of spinal stenosis.[23]

Foraminotomy

Foraminotomies constitute a category of lumbar decompressive procedures designed to relieve compression or pressure on spinal nerves in the neural foramen.[25,55] Distinct from laminectomies and discectomies, foraminotomies aim to preserve lamina integrity while providing precise relief from nerve compression.[56] This surgical approach is indicated for foraminal stenosis, a condition characterized by compression of a nerve root within the middle zone of the foramina, aiming to effectively address this targeted area of nerve impingement.[57,58] Although spinal stenosis has been recognized since the early 1900s, it was not until the 1970s that a subset of patients with lumbar nerve root compression due to superior articular facet hypertrophy were identified, leading to the adoption of foraminotomies as a viable treatment option.

MINIMALLY INVASIVE LUMBAR DECOMPRESSION

While decompression was traditionally achieved through an open approach, the field of spine surgery underwent a paradigm shift in 1994 when Foley and Smith introduced the use of tubular retractors to facilitate the treatment of lumbar pathologies.[59] The integration of tubular retractors enabled surgeons to adopt a minimally invasive approach to help alleviate spinal pathology. Tubular retractors allow surgeons to systematically expose regions they need to access through the progressive dilation of soft tissue structures without having to directly make incisions through muscle, reducing the risk of chronic postoperative back pain due to intraoperative soft tissue damage.[60]

Minimally Invasive Laminotomy

The approach to laminotomies has gradually evolved, initially from an open approach, termed a classic laminotomy, to a more minimally invasive approach. The inception of unilateral and bilateral minimally invasive laminotomies,[23,53,54,61,62] in comparison to open approaches, has demonstrated shorter LOS, greater stability, lower wound complications, less estimated blood loss, postoperative opioid use, and shorter recovery times to baseline.[26,63] However, some studies have shown that while patients with minimally invasive laminotomies have a reduced risk of complications, there is not a significant difference in outcomes between open and MIS approaches.[63] While clinical outcomes are comparable between unilateral and bilateral approaches, unilateral laminotomies have been associated with lower estimated blood loss, shorter operative times, and improved postoperative radiographic stability, the latter of which may be attributed to the intervertebral translational motion induced by bilateral procedures.[54] Unilateral laminotomies also present a marginally higher risk of postoperative complications, such as epidural hematomas, incidental durotomies, and radicular deficits.[24,54] The increased rate of epidural hematomas may be attributed to decreased control of the contralateral epidural veins, while the increased rate of incidental durotomies has been attributed to the increased technical demand of the unilateral approach.[54]

Despite these challenges, minimally invasive unilateral laminotomies for bilateral decompression (ULBD) have increasingly become the preferred choice among surgeons due to its ability to provide adequate decompression while minimizing tissue dissection and trauma, decreasing operating time, and reducing damage to spinal structures and musculature.[53,64,65] While minimally invasive ULBDs have been associated with favorable patient outcomes, they are not without their limitations, including the need to dissect paravertebral muscles as well as poor visualization of the contralateral visual field.

Percutaneous Minimally Invasive Lumbar Decompression

Percutaneous minimally invasive lumbar decompression (MILD) was developed in 2005 by Drs. Solsberg and Schomer for patients with spinal stenosis who were unable to tolerate spinal surgery due to existing comorbidities.[27] MILD, which is conducted primarily with local anesthesia, offers a less invasive option compared with traditional laminotomies/laminectomies, involving the removal of portions of hypertrophied ligamentum flavum with a bone rongeur through a percutaneous port without the installation of implants. MILD is customarily preferred in patients with limited physiological resilience to more invasive procedures and is typically indicated for patients with imaging-confirmed stenosis secondary to ligamentum flavum hypertrophy ≥2.5 mm.[27] Contraindications include previous spinal surgery and infection at the site of potential surgery.[27] In 2016, the success of the MiDAS ENCORE randomized controlled trial (RCT) demonstrated MILD's effectiveness over epidural steroid injections for lumbar stenosis, leading to its approval for Medicare coverage beginning in 2017.[27,28,66]

Patients undergoing MILD have shown notable postoperative improvements in both pain and functionality. Across 5 studies, MILD patients have been shown to have a 41% improvement in visual analog scale (VAS) scores.[67–71] In terms of functional improvement, MILD patients in 1 study demonstrated a postoperative improvement in Oswestry Disability Index (ODI) scores by 16.5 points at 6 weeks, 16.2 at 3 months, 15.4 at 6 months, and 14.0 at 1 year.[67] MILD patients also demonstrated a low risk of adverse events intraoperatively, with the most common surgical complications being bleeding requiring blood transfusions and dural tears.[72]

With its efficacy and safety better understood, there has been an increase in the use of MILD as an early, first-line operative treatment strategy following failed conservative treatment for patients who are poor surgical candidates. With the expanding application of MILD, future research is needed to corroborate its utility against contemporary and customary treatment strategies.[27] Currently, the MOTION study, an RCT involving 150 patients, is assessing the efficacy of MILD compared with conventional medical management, while another prospective study is comparing the outcomes of patients treated with MILD compared with spacers. In addition to further comparative studies, improvements in the navigation technology and optical imaging used during MILD procedures will help increase its efficacy for treating lumbar spinal stenosis.[27]

ENDOSCOPIC LUMBAR DECOMPRESSION

In the 1980s, Parviz Kambin led the originative preliminary explorations of endoscopic approaches to lumbar spine surgery.[73] Endoscopic approaches have garnered substantial traction over the past decade with reduced operative times, enhanced visualization, reduced risk of paravertebral muscle injury, improved preservation of bony structures, less perioperative pain, and enhanced functional recovery.[74–78] These approaches typically employ interlaminar or transforaminal techniques, utilizing uniportal, biportal, or endoscopic systems.[79] Notably, the utilization of endoscopic approaches for several procedures have demonstrated particularly promising outcomes, including endoscopic microdiscectomy, endoscopic unilateral laminotomy for bilateral decompression (ULBD), and transforaminal endoscopic lumbar foraminotomy (TELF; Table 2).

Endoscopic Microdiscectomy

In 1934, the first lumbar discectomy was performed utilizing an open approach to remove an intervertebral disc.[93] Consequently, in 1978, the introduction of an operating microscope marked a significant advancement, leading to the evolution of minimally invasive lumbar

Table 2. Summary features of endoscopic lumbar decompression.[22,24,64,76–92]

Procedure	Summary Features
Endoscopic Microdiscectomy	Indications ● Lumbar disc herniation resulting in neurological deficits and radiculopathy not responding to conservative management Contraindications ● Severe facet joint arthritis or active infection ● Severe central canal stenosis requiring extensive decompression than provided by microdiscectomy Approaches ● Interlaminar or Transforaminal Advantages ● Reduced soft tissue and bony trauma ● Smaller incision and improved visualization of the surgical site ● Shorter LOS in hospital and faster recovery Disadvantages ● Steep learning curve ● Potential for limited access to complex herniations or multi-level diseases increasing risk of incomplete decompression
Transforaminal Endoscopic Lumbar Foraminotomies (TELF)	Indications ● Foraminal stenosis with nerve root compression ● Lateral recess stenosis caused by disc herniation Contraindications ● Necessity for more extensive decompression due to severe central canal stenosis ● Severe facet joint arthritis or active infection Approaches ● Transforaminal Advantages ● Improved visualization of neural structures along with smaller incisions resulting in reduced soft tissue trauma ● Enhanced preservation of structures around surgical site and improved postoperative spinal stability Disadvantages ● Reduced access to central canal ● Challenging to achieve full decompression in severe cases of foraminal stenosis
Endoscopic Unilateral Laminotomy for Bilateral Decompression (ULBD)	Indications ● Symptomatic disc herniation not responding to conservative management ● Lumbar spinal stenosis resulting in bilateral neural compression Contraindications ● Severe central canal stenosis requiring more invasive approaches to achieve adequate decompression ● Significant spinal instability such as vertebral fractures or severe spondylolisthesis ● Severe facet joint arthritis or active infection Approaches ● Typically interlaminar Advantages ● Preservation of contralateral structures due to unilateral approach for bilateral decompression ● Smaller incisions, reduced soft tissue trauma, quicker recovery, and shorter in hospital LOS Disadvantages ● Steep learning curve ● Limited access to central canal

Abbreviations: LOS, length of stay; TELF, transforaminal endoscopic lumbar foraminotomies; ULBD, unilateral laminotomy for bilateral decompression.

microdiscectomies, which demonstrated comparable outcomes to conventional open discectomies.[93] Further innovation occurred in the 1990s with the development of an endoscopic technique.[22,94]

Data from current literature present promising outcomes for patients undergoing endoscopic discectomies compared with open and microsurgical approaches, as evidenced by several RCTs. Mayer and Brock conducted an RCT with 40 patients and showed that at 2 years postoperatively, those undergoing transforaminal endoscopic percutaneous lumbar discectomy displayed superior rates of symptom resolution (80% vs 65%) and higher rates of return to work (96% vs 72%) compared with patients who underwent microsurgical discectomy.[95] In an RCT involving 143 patients comparing outcomes between patients undergoing transforaminal endoscopic discectomy (TED) and microdiscectomy, Gibson et al demonstrated that while both cohorts experienced significant improvements in all outcome measures, patients undergoing TED had significantly reduced hospital stay and affected side leg pain at 2 years.[96] However, TED patients had a 2-times higher risk of revision at 2 years compared with microdiscectomy patients. Ruetten et al, in an RCT with 178 patients, found similar ODI, VAS-back, and VAS-leg scores at 2 years with no significant difference in symptom recurrence between patients undergoing lumbar discectomies utilizing a full-endoscopic interlaminar technique and those undergoing surgery with a microsurgical technique.[97] Furthermore, in a multicenter RCT involving 613 patients, Gadiradj et al reported significantly reduced VAS-back, ODI, and VAS-leg pain scores at 12 months postoperatively in patients undergoing full endoscopic discectomy compared with open discectomy for sciatica.[84]

Although current literature shows promising results for endoscopic microdiscectomies compared with open and microsurgical techniques, further high-quality prospective studies are needed to elucidate long-term outcomes.

Endoscopic ULBD

While minimally invasive ULBD has shown promising outcomes, it still requires the dissection of paravertebral muscle and provides suboptimal visualization of the contralateral visual field. To overcome deficiencies, there has been an attempt to integrate the use of an endoscope for ULBDs.[64,85–87] Endoscopic ULBDs can be subdivided into different approaches: inside-out, outside-in, and contralateral.[80,81]

Compared with minimally invasive ULBDs, several studies have shown the benefits of endoscopic ULBD, including reduced hospital LOS and improved patient-reported outcomes such as lower ODI and VAS leg pain scores at 1 year.[82,83,98] In a retrospective study of 93 patients, with 42 undergoing endoscopic ULBD and 51 undergoing minimally invasive ULBD, Chen et al found that patients who underwent endoscopic ULBD experienced significantly reduced VAS scores for back pain, less blood loss, shorter hospitalization, and decreased analgesic use.[98] Similarly, in another retrospective study of 60 patients comparing outcomes between patients who underwent endoscopic vs minimally invasive ULBD, Kim et al demonstrated significant postoperative improvements in ODI, VAS, and MacNab scores in both cohorts, with greater improvement in the endoscopic group.[83]

The widespread adoption of endoscopic ULBDs as a standard practice has encountered several obstacles, including the demand for extensive training, longer operating room times, and specialized equipment.[64,82,99] Despite these challenges, endoscopic ULBDs have shown notable advantages over conventional open and minimally invasive laminotomies, including reduced LOS and improved postoperative VAS leg pain scores and back pain disability index scores.[80,81,100] The increasing preference for endoscopic ULBDs has spurred ongoing technical advancements, including the improvement of endoscopic systems designed to mitigate disruption of the interspinous ligament and facet joints.[53,100] These advancements further contribute to the procedure's evolving efficacy and safety profile.

Transforaminal Endoscopic Lumbar Foraminotomies

Similar to other procedures, endoscopic foraminotomies have gained increased popularity compared with traditional approaches to foraminotomy due to their high effectiveness and superior preservation of soft tissue and bony structures. Specifically, TELF enables exploration of the intervertebral foramen, facilitating the ablation of epidural fibrosis, resection of herniated intervertebral discs, and removal of osteophytes.[25,101] Furthermore, TELF is recognized as a safe alternative to fusion for patients suffering concurrently from spondylolisthesis and foraminal stenosis.[55]

TELF presents a less invasive solution for spinal nerve root compression in conditions such as lumbar foraminal stenosis and herniated nucleus pulposus.[56,57] Studies have reported TELFs to have a success rate of 78%–90% with a low risk of adverse events, which is attributed to postoperative increases in foraminal height and area, thus reducing nerve compression.[57,58] However, their effectiveness varies depending on the type of radiculopathy and location of foraminal stenosis.[102] In a retrospective review of 220 patients, Lewandrowski et al found less favorable outcomes for entry zone foraminal stenosis, likely attributable to the predisposition of the entry zone to exhibit "hypertrophy of the superior articular facet."[29,102] Consequently, TELFs are most beneficial for middle and exit zone foraminal stenosis and contained herniated discs.

Laser-assisted endoscopic foraminotomies represent a novel technique, enhancing the precision of bone and tissue removal. Early case series show promising results, with improvements observed in both VAS and ODI scores.[103] Its highly targeted approach to decompression makes TELF a viable alternative to fusion surgery or open foraminal decompression, especially for older adults or medically compromised patients, as it does not require a repeat posterior approach and can be done under local anesthesia.[57] Nevertheless, comparative studies on endoscopic foraminotomy outcomes for lumbar decompression are limited, underscoring the need for further investigation.

Limitations of Endoscopic Approaches

Despite several notable benefits, including faster recovery times and reduced iatrogenic injury to surrounding soft tissue and bony structures, endoscopic approaches also have a few notable limitations, including the need for specialized training and equipment. Additionally, both open and minimally invasive approaches provide distinct advantages depending on patient pathology and medical history. For instance, an endoscopic approach is preferred for laminotomies when treating patients with smaller herniations, less severe stenosis, or those with contraindications to open surgery. Conversely, open laminotomies are favored for larger lumbar herniations or more severe spinal stenosis, where extensive tissue or bone removal is necessary to achieve adequate decompression.[88]

While promising outcomes associated with endoscopic techniques have resulted in advocacy for their use over minimally invasive and open approaches, the intense training and specialized equipment required for endoscopic surgery represent a limiting factor.[22] The adoption of endoscopic techniques has progressed more rapidly in Asia, where a large proportion of procedures are now conducted using an endoscopic approach.[22] However, there has been a delayed transition in the United States, attributed in part to increased regulations preventing trials needed to assess the efficacy of these techniques. Furthermore, it is important to consider challenges, including increased capital cost, decreased intraoperative visualization, and the steep learning curve required to effectively implement endoscopic spine surgery.[22]

FUTURE OF LUMBAR DECOMPRESSION

In the coming years, the demand for lumbar decompression surgery is expected to rise. The use of endoscopic techniques is most prevalent in Asia, with over 80% of the current literature on endoscopic lumbar surgical approaches coming from the region. However, the United States and other regions have been slower to adopt these techniques due in part to increased regulations.[22] The future of lumbar spine surgery appears to be moving away from traditional open approaches and toward endoscopic methods. The progression of this shift is largely attributed to technological innovations, specifically the adoption of navigation systems. Navigation systems provide surgeons with more accurate intraoperative anatomical guidance than standard 2-D fluoroscopy and enhance the accuracy of instrument placement and pedicle screw fixation. The transition from optic to electromagnetic navigation systems is also promising, reducing radiation exposure and operation time without compromising outcomes.[84,96,97]

Robotic-assisted surgery is another area expected to grow in the coming years, potentially easing the learning curve for endoscopic surgery. Robots are capable of accurately placing endoscopes, helping with preoperative mapping and assisting with pedicle screw fixation, leading to improved patient outcomes.[80,84–87] Several recent studies have even shown improved outcomes for patients with pedicle screw fixation carried out in surgeries with robots compared with surgeries without robots.[89–92] For laminotomies, robotic assistance during surgery has been shown to minimize human error by helping plan the laminotomy map and entry point, identifying the location of the interlaminar window, and executing precise drilling depths.[104]

Augmented and virtual reality are anticipated to transform spine surgery even further. Virtual reality systems can improve surgical planning and training, while augmented reality offers real-time, head-mounted displays that combine navigation data with operative views to optimize surgical safety and efficiency.[89] Furthermore, augmented reality has been shown to aid in pedicle screw fixation, including helping to find entry points and ideal trajectories similar to standard navigation systems.[89,92,105,106] There are currently 3 augmented reality devices on the market for spine surgery, including Augmedics XVision, Microsoft HoloLens, and Immersive Touch.[92]

CONCLUSION

Lumbar decompression, driven by advancements in technology and surgical training, will continue to evolve. The integration of new technologies like navigation systems, robotic assistance, and augmented reality is expected to refine current procedures, optimize treatment, and improve patient outcomes.

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